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STAINLESS STEEL

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ABSTRACT OF THE DISCLOSURE

This invention relates to a stainless steel and a method for producing the same, whereby material particularly adapted for use in structural applications such as the manufacture of cargo boxes is achieved. Specifically, the material is characterized by an improved combination of strength and toughness that is achieved by producing hot-band material having a substantially martensitic microstructure of a composition consisting of .10 max. percent carbon, 2 max. percent manganese, 1 max. percent nickel, 9.5 to 13.5 percent chromium, and the balance iron. This material has a maximum titanium to carbon ratio of about 8. With titanium to carbon ratios of between 4 to 8, nickel must be present within the range of .5 to 1 percent. For optimum weld-toughness the maximum titanium to carbon ratio is about 4, either with or without nickel. To achieve the desired combination of strength and toughness, the material in hot-band gage is annealed for a time at temperature to achieve a hardness of at least 80 R_b and preferably 82 to 92 R_b.

This is a division of Application Ser. No. 732,542, filed May 28, 1968, and now issued U.S. Pat. 3,778,316.

For the purpose of satisfying various structural applications, a low-cost stainless steel having a combination of high strength and toughness, while exhibiting satisfactory formability, corrosion resistance and weldability, is desired. Such a material is particularly adapted to the manufacture of cargo boxes for ocean shipping. More specifically, steels for such structural applications are required to be readily formable and weldable without pre- or post-heat treatment. The strength requirements vary with gage but generally such material should have a minimum tensile strength of 65,000 p.s.i. in combination with a minimum yield strength of 45,000 p.s.i., while exhibiting an elongation in 2 inches of a minimum of 20 percent. The material should possess good notch toughness and have at heavy gages a ductile-to-brittle impact transition temperature below 0° F. The material must not only be weldable but must exhibit weld toughness. Weld toughness is essential because structures such as cargo boxes are subjected at the joints to impact loads during service, and improper welding or inadequate weld properties can result in cracking at any notch defects. The corrosion-resistance requirements are not especially stringent; however, the corrosion resistance must be at least sufficient to make possible the use of low-cost paint systems. Conventional low-alloy high-strength steels used for these particular applications, prior to the present invention, required extensive surface preparation and special protective paints, which of course is avoided by using stainless steel produced in accordance with the present invention.

It is, accordingly, the primary object of the present invention to provide a stainless steel characterized by a combination of good strength, toughness, formability, weldability, and corrosion resistance.

Another more specific object of the invention is to provide a stainless steel characterized by a minimum tensile strength of 65,000 p.s.i., a minimum yield strength of 45,000 p.s.i., a transition temperature below 0° F. for .25 in. thick material, and a minimum elongation in 2 inches of 20 percent, with good weldability and adequate corrosion resistance.

Still another object of the invention is to provide a stainless steel having a good combination of high strength and toughness, said material being weldable without pre- or post-heat treatment and said weld heat-affected zone being characterized by good toughness and thus good resistance to cracking upon exposure to impact loads during service.

Yet another object of the invention is to provide a method for producing stainless steel characterized by a combination of high strength and toughness, with good welding properties, by producing as-hot-rolled material having a substantially martensitic microstructure, and thereafter annealing said material for a time at temperature to achieve a hardness of at least 80 R_b and preferably within the range of 82 to 92 R_b.

These and other objects of the invention, as well as a complete understanding thereof, will be apparent from the following description and examples of the invention.

In accordance with the present invention, a steel of the following composition in weight percent is provided:

Carbon	.10 max.
Manganese	2 max.
Nickel	1 max.
Chromium	9.5 to 13.5.
Titanium	Max. 8 times carbon percent.
Iron	Balance.

With titanium to carbon ratios of between 4 to 8, nickel should be present within the range of .5 to 1 percent. This is necessary to obtain sufficient martensite in the steel for the purposes of the invention. The relatively high titanium content within this range combines with carbon to promote ferrite, and thus nickel is required to counter this effect of high titanium.

Within the above-stated broad range, the following preferred ranges may be employed:

Carbon	.03 to .08.
Manganese	1 max.
Silicon	.5 max.
Nickel	1 max.
Chromium	10.5 to 12.5.
Titanium	Max. 4 times percent carbon.
Nitrogen	.03 max.
Iron	Balance.

Within the above composition limits nickel may be present within the range of .5 to 1 percent. Titanium may be present within the range of .12 to .32 percent. Within these ranges, nickel and titanium may be used singly or in combination.

For the above-listed stainless steels to exhibit the required toughness, it is necessary that they have a substantially martensitic microstructure upon hot rolling to hot-band gage. Thereafter, to produce the required strength, the material in hot-band gage must be annealed at a time at temperature to achieve a hardness of at least about 80 R_b and preferably 82 to 92 R_b. It has been found, as will be demonstrated by specific examples reported hereinafter, that by annealing to a hardness within this range the above-listed stainless steel compositions will exhibit the required minimum strength. Specifically, minimum tensile strengths of 65,000 p.s.i. in combination with minimum yield strengths on the order of 45,000 p.s.i. with a minimum elongation in 2 inches of 20 percent are produced. As will be demonstrated by the specific examples reported hereinafter, the substantially martensitic structure prior to annealing is necessary to achieve the desired toughness in combination with high strength.

The required substantially martensitic hot-band microstructure is achieved by providing stainless steel within the composition limits, and particularly by adhering to the recited titanium to carbon ratio, after hot rolling the as-hot-rolled material is characterized by a substantially martensitic microstructure, and consequently upon annealing it exhibits the required toughness.

To establish the criticality of the martensitic microstructure in the practice of the invention in achieving the required toughness, a steel was produced within the composition limits of the invention, except that the titanium to carbon ratio was 12 to 1 and thus provided a ferritic hot band. Upon annealing, the steel exhibited an impact transition temperature of 50° F., which signifies poor notch toughness.

To specifically demonstrate the present invention, four stainless steel compositions as listed in Table I were melted.

TABLE I

Heat No.	Composition, percent									
	C	Mn	Si	Ni	Cr	Mo	Cu	Al	Ti	N
2232	.07	.56	.20	.89	11.70	------	.19	.014	.20	.027
2218	.07	.54	.24	.74	12.03	.22	.19	.013	.23	.016
2217	.041	.38	.32	.25	12.46	.12	.21	.01	[1] ND	.022
2223	.056	.54	.28	.78	11.78	.22	.18	.01	[1] ND	.024

[1] Not detectable when analyzed.

The compositions of Table I were processed in the conventional manner from ingot to hot-band gage. Materials were hot rolled, at a temperature of about 2100 F., to a hot-band gage of about .250 inch. Samples of the materials in hot-band gage were then subjected to the various annealing treatments as listed in Table II.

To illustrate annealing practices both within and without the scope of the invention and to establish the relationship between the annealed hardness of steel produced in accordance with the present invention and the required strength levels, various stainless steel compositions, within the composition range of the invention, were melted and subjected to various anneals as reported in Table III. The hardness values for each of these samples is recorded for comparison with the yield and tensile strength of each sample. From a comparison of the hardness values with the tensile properties for a particular sample, it may be seen that the desired strength levels are achieved in all instances wherein the hardness values are at least 80 R_b and preferably within the range 82 to 92 R_b. All of the samples exhibited a substantially martensitic microstructure in the hot-band gage, and thus, as reported in Table III, the toughness of the samples was excellent. However, as may be seen from Table III, to achieve the required combination of strength, ductility and toughness, proper annealing to achieve a hardness of at least 80 R_b must be provided.

It will be understood, of course, that the specific annealing conditions required in the practice of the invention, particularly with regard to time and temperature, will depend on various factors, such as the mass and in particular the composition of the steel being treated. As may be seen from Table III, either strand or box annealing may be employed in the practice of the invention. All that is necessary in such practice is to determine the annealing conditions for a particular material that will achieve an annealed hardness of at least 80 R_b. If this condition is obtained during annealing and if the composition

TABLE II

Heat No.	Condition	Hardness, R_b	Longitudinal tensile-data			Impact transition temperature
			0.2% offset, yield strength (p.s.i.)	Tensile strength (p.s.i.)	Percent elongation in 2 in.	
2232	Box-annealed 1,400 F.	86	53,600	76,200	26.0	Below −80 F.
2218	Box-annealed:					
	1,400 F.	92	72,500	87,900	25.0	
	1,475 F.	82	54,300	77,000	33.5	−50 F.
2217	Strand-annealed 1,500 F.	84	52,200	80,600	23.5	Below −70 F.
	Box-annealed 1,400 F.	77	37,400	65,300	29.0	
2223	Box-annealed 1,400 F.	86	53,700	80,000	27.5	

It may be seen from the data reported in Table II that, by annealing to achieve hardnesses within the range above recited, the required strength levels are achieved. All of these steels were characterided by a substantially martensitic microstructure in the as-hot-rolled condition, which resulted after annealing in excellent toughness as reported in Table II.

of the steel is within the ranges recited hereinabove to achieve a substantially martensitic microstructure in hot-band gage, then the required combination of high strength and toughness will be achieved.

The proper annealing treatment for the purposes of the invention is governed by the composition of the steel, as demonstrated by the data presented in Table IV.

TABLE III

Heat No.	Condition	Hardness, R_b	Longitudinal tensile-data			Impact transition temperature (° F.)
			0.2% offset, yield strength (p.s.i.)	Tensile strength (p.s.i.)	Percent elongation in 2 in.	
1C25	Box-annealed 1,400 F.	76	41,300	66,100	31.0	
2216	Box-annealed 1,475 F.	78	40,400	66,500	33.5	
2216	Box-annealed 1,400 F.	80	42,600	69,500	31.5	
2226	Box-annealed 1,500 F.	80	47,300	72,300	30.5	
2218	Box-annealed 1,475 F.	82	54,300	77,000	33.5	−50.
2217	Strand-annealed 1,500 F.	84	52,200	80,600	23.5	Below −70.
2232	Box-annealed 1,400 F.	86	53,600	76,200	26.0	Below −80.
2227	Strand-annealed 1,600 F.	88	59,200	82,500	21.0	Below −60.
2224	Box-annealed 1,400 F.	90	65,100	85,300	26.0	Do.
2218	do	92	72,500	87,900	25.0	

TABLE IV

Nickel-bearing steels

Titanium/carbon ratio below 4

Material	Condition	Hardness (R_b)
Heat 2218, 0.74 Ni, 3.3 Ti/C.	As-hot-rolled	107
	Strand-annealed:	
	1,400 F	103
	1,500 F	101
	1,600 F	106
	Box-annealed:	
	1,400 F	92
	1,425 F	87
	1,475 F	82
	1,525 F	84
	1,575 F	75
	1,625 F	77

Titanium/carbon ratio of 4 to 7

Material	Condition	Hardness (R_b)
Hear 2216, 0.77 Ni, 5.2 Ti/C.	As-hot-rolled	100
	Strand-annealed:	
	1,400 F	101
	1,500 F	99
	1,600 F	99
	Box-annealed:	
	1,400 F	80
	1,425 F	78
	1,475 F	78
	1,500 F	77

Titanium/carbon ratio of 7 to 8

Material	Condition	Hardness (R_b)
Heat 1B94A, 7.3 Ni, 8.2 Ti/C.	As-hot-rolled	97
	Strand annealed:	
	1,300 F	93
	1,400 F	90
	1,450 F	82
	1,550 F	80
	1,600 F	80
	1,650 F	81
	1,700 F	80
	Box-annealed:	
	1,575 F	72
	1,625 F	71

Non-nickel-bearing steels

Material	Condition	Hardness (R_b)
Heat 2232, 2.9 Ti/C.	As hot-rolled	106
	Strand-annealed:	
	1,400 F	102
	1,500 F	99
	1,600 F	92.5
	1,700 F	103
	Box-annealed:	
	1,400 F	86
	1,500 F	72

Material	Condition	Hardness (R_b)
Heat 1C25, 5.2 Ti/C.	As-hot-rolled	86
	Strand-annealed:	
	1,200 F	87
	1,300 F	87
	1,400 F	86
	1,500 F	85
	Box-annealed:	
	1,400 F	76
	1,575 F	62
	1,625 F	66

The nickel content of the steel and the titanium to carbon ratio are particularly important, because these factors control the amount of martensite in proportion to ferrite in the steel and its tempering behavior. In general, the lower the nickel content and the higher the titanium content, the higher will be the ferrite content. In addition, the presence of nickel in more than a residual amount retards softening of the martensite in the steel during annealing. With nickel-bearing steels, wherein nickel is present in more than a residual amount, the annealing temperature required to achieve the desired strength levels depends primarily upon the specific ferrite-martensite balance, which is in turn determined by the titanium to carbon ratio. More specifically, for nickel-bearing steels with a titanium to carbon ratio below 4 box annealing at a temperature within the range of 1400 to 1500 F., which is near the lower critical temperature of the steel, is required. The nickel-bearing steels with titanium to carbon ratios of about 4 to 7 contain more ferrite and thus to achieve the desired strength they must be box annealed at a lower temperature within the range of 1200 to 1400 F. Nickel-bearing steels having titanium to carbon ratios between about 7 and 8 contain substantial ferrite, and strand annealing within the temperature range of 1500 to 1700 F. is required. For these high-titanium steels the rapid softening due to the increased ferrite content precludes the use of box annealing to achieve the desired strength level. Non-nickel-bearing steels soften more rapidly as compared to nickel-containing steels of the invention. Consequently, to obtain the required strength levels either box annealing at 1200 to 1400 F. or strand annealing at 1200 to 1600 F. should be used. Non-nickel-bearing steels are considered to be those having a nickel content no greater than a residual amount, which is typically a maximum nickel content of about .25 percent.

TABLE V

Material Heat No.	Ti to C ratio	Impact transition temperature in weld heat-affected zone, F.
139011	3.7	−30
1B94A	8.2	50
128392	12	150

Table V shows that to achieve weld toughness, the titanium to carbon ratio should be at the above-stated preferred maximum of about 4. It should be understood, however, that all the steels produced in accordance with the invention are readily weldable without pre- or post-heat treatment and have satisfactory weld-formability. For example, butt welds can be bent 180 degrees without cracking. In Table V, the steels reported had compositions within the limits of the invention, as recited herein, except for the titanium to carbon ratio for material Heat No. 128392.

It is understood that other adaptations and modifications of the invention may be made by those skilled in the art without departing from the scope and spirit of the appended claims.

What is claimed is:

1. A hot-rolled and annealed stainless steel characterized by an improved combination of strength and toughness and having after hot rolling a substantially martensitic structure, and having after annealing a hardness of at least about 80 R_b, said steel consisting essentially of, in percent, .10 max. carbon, 2 max. manganese, 1 max. nickel, 9.5 to 13.5 chromium, max. titanium 8 times percent carbon with nickel being present within the range of .5 to 1 when titanium is present in an amount greater

than 4 times the carbon content, and the balance iron and incidental impurities.

2. A hot-rolled and annealed stainless steel characterized by an improved combination of strength and toughness and having after hot rolling a substantially martensitic structure and an annealed hardness of at least about 80 R_b, said steel consisting essentially of, in weight percent, .03 to .08 carbon, 1 max. manganese, .5 max. silicon, 10.5 to 12.5 chromium, max. titanium 4 times percent carbon, 1 max. nickel, and the balance substantially iron and incidental impurities in amounts not substantially affecting the properties.

3. The steel of claim 2 having nickel within the range of .5 to 1.

4. The steel of claim 2 having titanium within the range of .12 to .32.

5. The steel of claim 2 having nickel within the range of .5 to 1 and titanium within the range of .12 to .32.

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